REMEDIATION TECHNOLOGIES FOR CONTAMINATED SOILS

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REMEDIATION TECHNOLOGIES FOR CONTAMINATED SOILS

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REMEDIATION TECHNOLOGIES FOR CONTAMINATED SOILS

A. Introduction

The purpose of this report is to provide a brief overview and description of technologies which are commercially available and are most often considered for soil remediation. The information is based on an in-depth review of recent literature, proceedings from workshops, and discussions with proponents of remediation technologies.

Large numbers of contaminated soils are a result of accidental spills from petroleum hydrocarbon products ranging from light refined products to heavy crude, tank bottoms and used oil. Many of the problems related to contaminated sites have been caused by leakages from underground and above ground storage tanks as well as other facilities for storing and transferring petroleum fuel products at service stations and power generating plants.[1] There are also contaminated soils with a wide range of industrial chemicals including pesticides, industrial solvents, inorganic acids and bases and liquid wastes containing heavy metals.

The remediation technologies can be classified into two categories:[1]

- In-situ technologies which remediate soil in its original location without any action taken to remove or excavate;

- Ex-situ technologies which allow for the treatment after the soil is excavated and removed from the ground.

In-situ technologies may involve any one or more of the following treatments:

- volatilization
- steam/heat stripping
- bioremediation
- soil leaching
- isolation/containment
- vitrification

Ex-situ technologies may involve any one or more of the following treatments:

- surface bioremediation
- enhanced bioremediation
- soil slurry bioreactor
- low temperature stripping
- high temperature thermal destruction
- beneficial reuse
- chemical extraction (soil washing)
- solidification/stabilization

Additional comments on bioremediation are included in Appendix A.

In-situ Technologies

Five of the in-situ technologies involve physical, chemical or biological treatment of the contaminated soil.

Volatilization is a simple evaporation process which removes the contaminant by forcing air through the pores of the affected soil. The process is usually referred to as air stripping or sparging.

Steam/heat stripping is another method of volatilization where heat is used to enhance the removal of less volatile contaminants with air stripping.

Bioremediation is basically an aerobic process to stimulate the natural bacteriological activity to degrade the contaminants in the soil. This involves providing favourable conditions for the bacteria to thrive with the use of proper nutrients, moisture and temperatures.

Soil leaching (flushing) involves spraying in-place contaminated soil with a mixture of water and additives. As the mixture percolates through the soil, the additives help to release the contaminants adsorbed on the soil surface.

Vitrification is a process which utilizes electrical heat to melt the contaminated soil and convert it into a chemically inert and stable glass-like material.

The sixth technology is soil isolation and containment. It is a method to install capping or construct subsurface barrier walls around the affected area to prevent the entry of water and provide a physical boundary to retard the migration of the contaminant. This technology does not remove or reduce the amount of the contaminant but rather prevents its migration from the site. This technology is not normally considered as a permanent solution as it may require long-term monitoring.

Ex-situ Technologies

Each one of these technologies involve the removal of the contaminated soil by excavation and transport to another location on-site for treatment. After treatment, the soil is

used for backfilling or hauled off-site for disposal at a non-hazardous waste landfill.

Both the surface bioremediation and enhanced bioremediation rely on natural processes involving bacterial activity to destroy the contaminants such as in the case of petroleum hydrocarbons where the bacterial action reduces them to carbon dioxide and water. In surface bioremediation, the contaminated soil is spread in layers of 15 cm to 60 cm on a level ground. Water, nutrients and if necessary, bacterial cultures are applied to provide conditions suitable for accelerated degradation. The soil is frequently aerated by tilling to expose the subsurface soil to oxygen and nutrients. This technique is called landfarming and has been used successfully by the oil refining industry for the treatment of oil sludges, tank bottoms and crude oil accidentally released from pipelines.[1,2,3]

Enhanced bioremediation is a process in which the contaminated soil is treated under controlled conditions with a uniform distribution of water, oxygen and nutrients to stimulate bacterial activity. This may involve the use of slurried soils, bioreactors or bioleaching which utilizes injected air and sprinkling of water to add oxygen and nutrients.

Low temperature stripping involves the heating of the contaminated soil to 200°C to 260°C to evaporate the contaminant from the soil. The technology is suitable for only light and moderate petroleum hydrocarbons which can be volatilized in a relatively short period of time. This technique does not result in the destruction of the hydrocarbon but the chemical is collected or recovered in the air emission control system.

High temperature thermal treatment involves the actual destruction of the contaminants by burning the soil within a confined system employing various sources of heat and soil handling techniques, usually in the range of 800°C to 1,200°C.

Beneficial reuse of contaminated soil means that the contaminated soil will be incorporated as a part of hot mixed asphalt used for paving. In some cases, this is a viable option because the asphalt is a mixture of hydrocarbons, sand and gravel.

Chemical extraction involves the separation of sludge/soils into their respective fractions by mixing the sludge/soil with a chemical extracting agent. This is also called soil washing.

Solidification/stabilization treatment involves addition of materials when combined physically or chemically with the contaminated soil or sludge to reduce the mobility of the contaminant. Solidification is a process in which sufficient quantity of solidifying agent (cement) are added to contaminated soil to produce a solid mass of material with high structural integrity. Stabilization involve the addition of reagents to render the contaminants less soluble and less mobile in the soil. Both solidification and stabilization processes do not necessarily change the chemical characteristics of contaminants in the soils being treated.

Ex-situ isolation/containment involves encapsulation of excavated soil. This is achieved by installing an engineered surface containment system. This is similar to a vault with a liner beneath the soil to prevent the downward or lateral movement of the leachate and a suitable impervious cover to minimize the infiltration of rain. The process attempts to isolate the excavated contaminated soil from the environment

by preventing the downward or lateral migration of contaminants in the leachate.

B. Detailed Analysis of Technologies

In-situ Technologies

1. Volatilization

This technology involves the removal of volatile organic contaminants from the subsurface soils by forcing air through the soil matrix. The basic components of the system include:

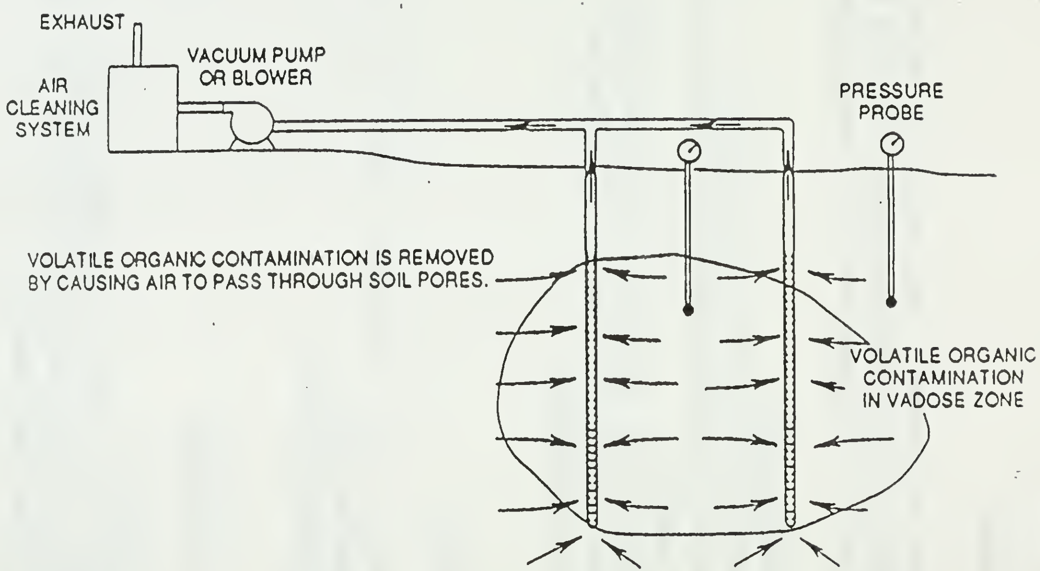
- extraction well;
- induced air draft fan or vacuum pump;
- screened perforated pipes to direct air flow through the soil matrix;
- treatment unit such as an activated carbon filter to remove contaminants from the air emissions;
- monitoring system.

Applicability

- gasoline, jet and diesel fuels from unsaturated subsurface area;
- degreasing solvents.[4]

Potential Advantages

- low costs;
- capable of removing hydrocarbon fuels from beneath buildings and paved areas without serious disruptions;
- low labour requirements.



IN SITU VOLATILIZATION PROCESS.

Adapted from ON-SITE TREATMENT SOIL 1989 MANUAL

Potential Limitations

- removes only volatile organic compounds;
- not effective for soils below water table;
- performance can be affected by soil conditions;
- removal efficiency determined by spacing and depth of vents.

Treatment Rate

- approximately 50 tons of soil per day.[2]

Estimated Costs

- costs range from $50 to $120 (US) per cu. yd. of affected soil but exhaust gas treatment systems may raise the costs drastically.[3]

2. Steam/Heat Stripping

This technology involves the removal of volatile contaminants by passing steam through the contaminated soil. Volatile organic carbons are transferred to the gaseous phase by steam distillation or vaporization. The contaminants may have to be removed from the air stream before venting to the atmosphere by appropriate air emission control devices such as condensers, carbon adsorption filters and/or thermal destruction systems;

Applicability

- volatile organic compounds such as phenol, vinyl chloride, chlorinated hydrocarbons, ammonia and hydrogen sulphide;

Potential Advantages

- very effective for certain chlorinated solvents such as methylene chloride;

Potential Limitations

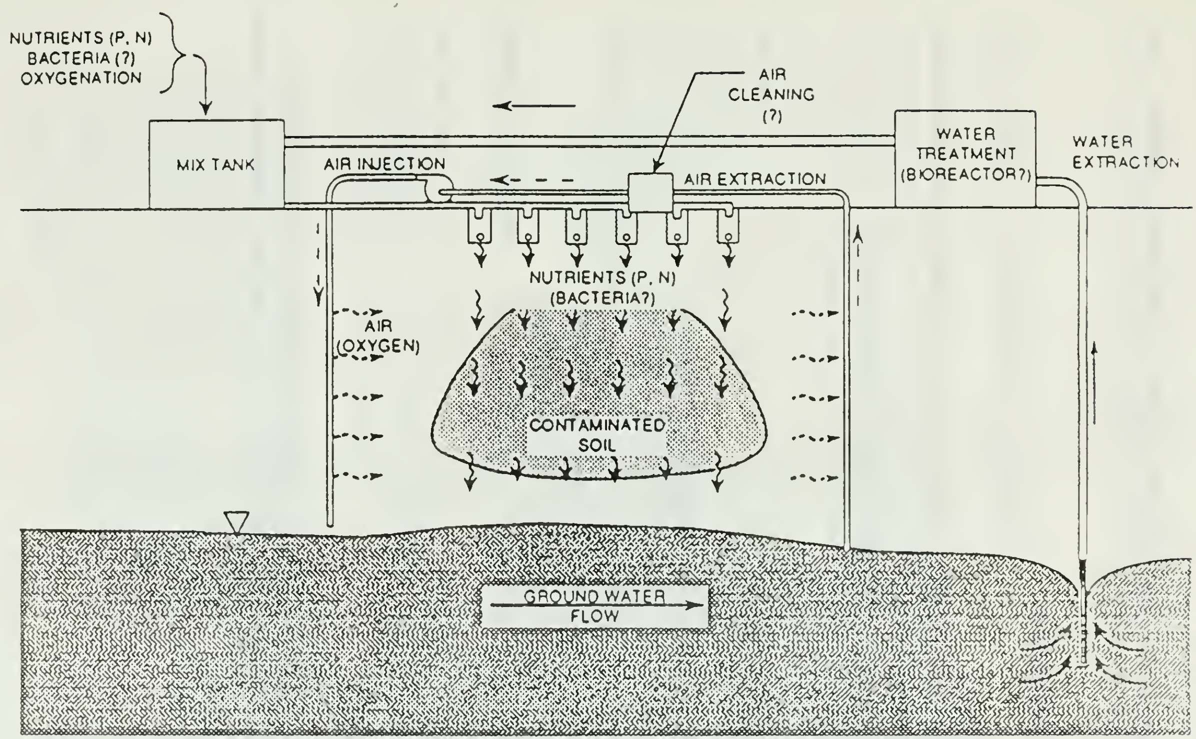
- high capital costs for steam generating and heat transfer equipment, and condensers.

Estimated Costs

- energy required to produce steam at 150°C will determine cost of process in excess of volatilization costs.

3. Bioremediation

The process involves the use of naturally occurring bacteria to degrade organic compounds in the soil to form carbon dioxide and water. Enhancement of the natural biodegradation process can be done by adding nutrients (nitrogen and phosphorus), oxygen and bacterial cultures.



IN SITU BIOREMEDIATION OF VADOSE ZONE.

Adapted from ON-SITE TREATMENT OF SOIL 1989 MANUAL

Applicability

Lighter petroleum hydrocarbons such as gasoline, diesel and heating fuels only.

Potential Advantages

- low costs;
- capable of being operated in areas not accessible for excavation;
- low manpower and maintenance requirements.

Potential Limitations

- may take years to remediate a site;
- low levels of cleanup may be difficult to attain;
- presence of heavy metals, high chlorinated organics, pesticides and herbicides may affect performance;
- possibility of contaminant migration;
- possibility of soil clogging thus decreasing soil porosity.

Treatment Rate

- degradation rates are site-and-contaminant-specific;
- desired objectives may take a few months to several years to attain.

Estimated Costs

- from \$15 to \$60 (US) per cu. yd.[2];
- \$50 TO \$100 (Cdn.) per cu. yd. (Northern Ontario).[5]

4. Soil Leaching (In-situ Soil Flushing)

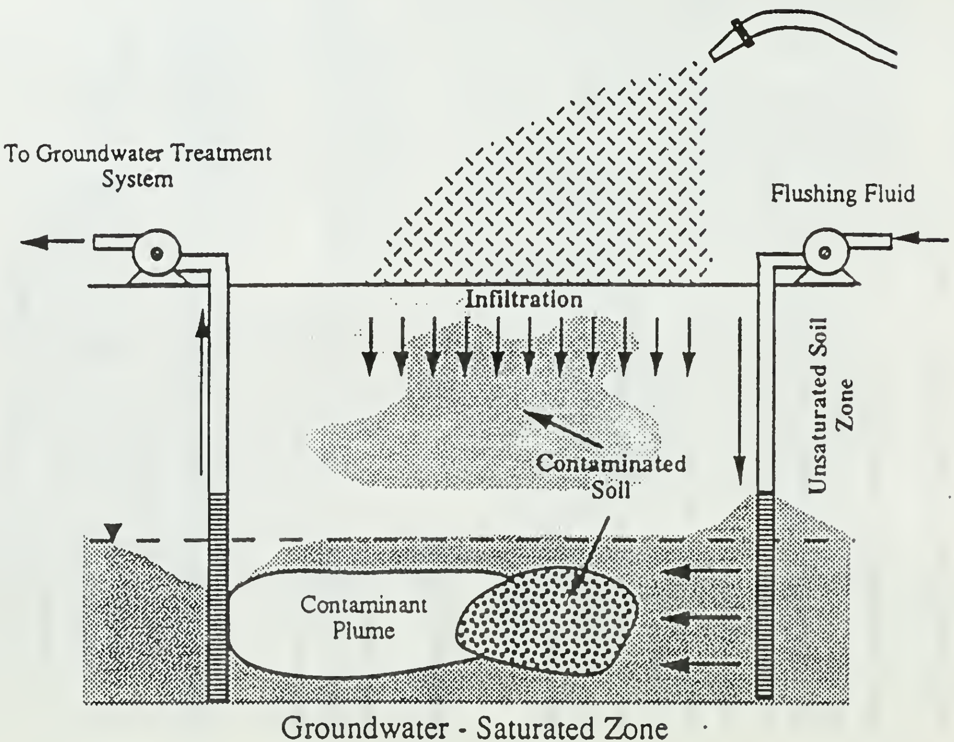
This technology involves injecting or flushing the soil with water to leach out contaminants in the soil. For petroleum hydrocarbons, non-toxic or biodegradable surfactants are added to the water to improve solubility and possible recovery. For heavy metals and inorganic contaminants, chemical reagents are added to the water to modify its pH or to enhance the solubility of contaminant. After the leaching, the water laden with the contaminants is sent to an on-site treatment plant for the removal of the contaminant. The purified water can be reused.

Applicability

Depending on the type of leaching additives and soil characteristics, the following chemical contaminants can be leached out from in-situ soils:[2]

- heavy metals (lead, copper, zinc, chromium);
- halogenated solvents (trichloroethylene, perchloroethylene);
- aromatics (benzene, cresols, toluene, phenols, xylenes);
- gasoline, fuel oils, diesel, crude oil;
- hydraulic and other viscous oils;
- PCBs and chlorinated phenols;
- oily sludges.

In Situ Soil Flushing



Adapted from SOIL REMEDIATION WORKSHOP

Potential Advantages

- low costs;
- minimum labour requirements;
- no need for excavation.

Potential Limitations

- difficult to confirm how well the objectives have been met;
- injection of some chemicals into the subsurface may not be acceptable;
- soil conditions must be ideal (e.g. low permeability clay type soils do not lend themselves to this technology);
- potential for contaminant migration beyond the affected area;
- large volumes of water and chemicals may be required.

Treatment Rate

- up to 50 tons per day of soil.[2]

Estimated Costs

- \$50 to \$120 (US) per cu. yd.[2]
- \$20 to \$50 (US) per cu. yd.[4]

5. Isolation/Containment

This technology involves the isolation of the contaminated soils from the surrounding area by installing an impervious surface cap (e.g. synthetic cover) and a barrier wall. This procedure does not destroy nor reduce the total amount of contaminants but it prevents their migration to the groundwater or escape into the atmosphere.

Applicability

Usually applied to sites with petroleum hydrocarbons but could be used for all sites.

Potential Advantages

- relatively low cost;
- process has been proven and commercially available.
- better control of contaminant migration.

Potential Limitations

- no reduction of contaminants;
- long term integrity of some materials are not well-established;
- depth limited to 3 to 5 meters;
- long term monitoring may be required.
- difficult for a large area.

Treatment Rate

- installation may require at least two to six months

Estimated Costs[2]

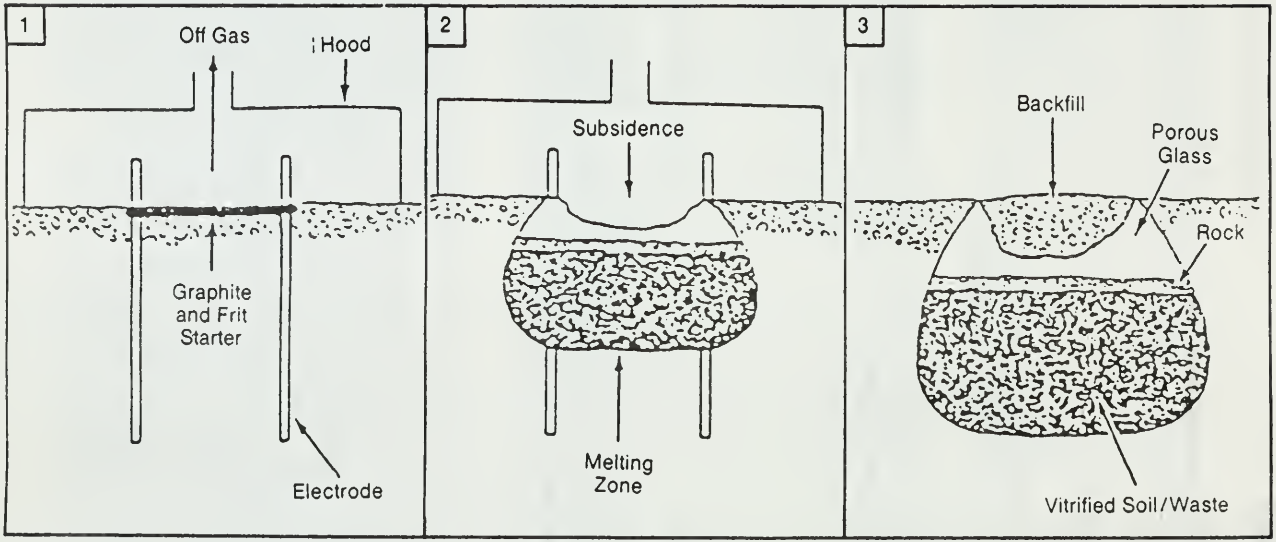
Costs may vary from $60 (US) per cu. yd. to well over $100 (US) per cu. yd. of soil contained.

Construction of a slurry trench using a backhoe may cost from $7 to $13 (US) per linear yd. Capping may cost $1 to $5 (US) per sq. ft.

6. Vitrification[1]

In-situ vitrification is a process by which the in-place contaminated soils are converted into a chemically inert stable glass and crystalline product through the use of electrical heat.

Four electrodes are inserted into the contaminated soil in a square pattern and a small quantity of a mixture of graphite and glass frit is placed in an "X" pattern on the soil surface. This provides a conductive path for the initial electrical current. When the electrical current is applied, heat is generated with the temperatures in the soil matrix reaching over 1,700°C. This causes the silica and aluminium oxides in the soil to melt. Any organic in the soil will be pyrolysed and resulting gases may combust at the surface when they come into contact with air. At the end of the specified time, all of the organics are destroyed. The electrodes are



(From PNL, 1986)

Adapted from REMEDIAL TECHNOLOGIES FOR UNDERGROUND STORAGE TANKS

removed from molten mass which is allowed to cool into a vitrified mass entrapping remaining contaminants.

Applicability

Contaminated soils with a wide range of chemicals:

- heavy metals and plating wastes;
- inorganics (fluorides, nitrates, chlorides and sulphates);
- PCBs;
- high boiling organics (PCBs, PAHs, tank bottoms, petroleum-based oils, heavy fuel oils, tank bottoms;

Potential Advantages

- process can treat simultaneously soils contaminated with mixed classes of chemicals (both organics and inorganics);
- treated by-product is not likely to have any environment or health impact.

Potential Limitations[2]

- cannot treat soils with high permeability;
- not suitable for soils located near groundwater and those with high organic content (over 10 percent);
- mercury will vaporize when exposed to vitrification temperatures;
- metal drums buried between electrodes may cause electrical short-circuit;

- soils with combustible liquids, low boiling liquids;
- depth up to 17 m.;
- expensive.

Treatment Rate

- average operation rate is approximately 3.4 to 5 tons per/hr.;[2]
- average processing operation may last about 150 to 200 hrs. depending on depth and spacing of electrodes.[2]

Estimated Costs

- $115 to $170 (US) per cu. yd.[1]
- $230 to $335 (US) per ton;[2]
- $275 to $400 (US) per ton;[3]
- costs vary with cost of electricity and moisture content of site.

Ex-situ Technologies

1. Surface Bioremediation

Surface bioremediation is a process in which naturally occurring bacteria are utilized to degrade the contaminants in the soil. This technique can be used effectively for soils contaminated with petroleum hydrocarbon fuels.

Surface bioremediation is also called land treatment or landfarming and involves the tilling and the cultivating of the soils to enhance biological degradation of hydrocarbons.

Excavated contaminated soil is spread over a treatment area in a layer usually 15 to 30 cm thick. The treatment area is properly designed for positive drainage and is surrounded by a soil berm to prevent runoffs. Agricultural fertilizer, water and bacteria, lime is added, if required. The soil is cultivated with a tiller, disc harrow or some other farm implement to mix with the soil bacteria, air and moisture. In some cases, a road grader is used.

Applicability

- petroleum hydrocarbon fuels (gasoline, diesel and heating fuels);
- oil sludges and tank bottoms;
- soils contaminated with polycyclic aromatic hydrocarbons.

Potential Advantages

- low to moderate costs;
- low labour requirements;
- can be effective on some heavier crudes.

Potential Limitations

- temperature dependent;
- presence of certain contaminants may be toxic to bacteria;
- air emissions control may be needed;
- may require large volumes of water to keep the soil moist;
- soil conditions may not be suitable (e.g. dense soils);
- may be difficult to attain required cleanup levels;
- large treatment area may be required;

Treatment Rate

- treatment time may require from about 2 months to 6 months and even longer;
- gasoline contaminated soils can be cleaned up from non-detectable to 500 ppb.

Estimated Costs

- \$10 to \$40 (US) per cu. yd.[3]
- \$15 to \$70 per cu. yd.[6]

2. Enhanced Bioremediation (Composting)

This is a process in which the bacterial action is accelerated by controlled treatment conditions with uniform distribution of water, oxygen and nutrients, chemicals for pH control, and temperature control. In some cases, a special culture of bacteria may be added along with soil amendments.

Contaminated soil is placed in a large pile over a number of perforated pipes laid out in parallel. The pile is sprinkled with a mixture of water surfactants and fertilizer. The air is drawn through the pile by a vacuum pump. In some cases, large wood chips are added as a bulking agent to facilitate the flow of air through the pile.

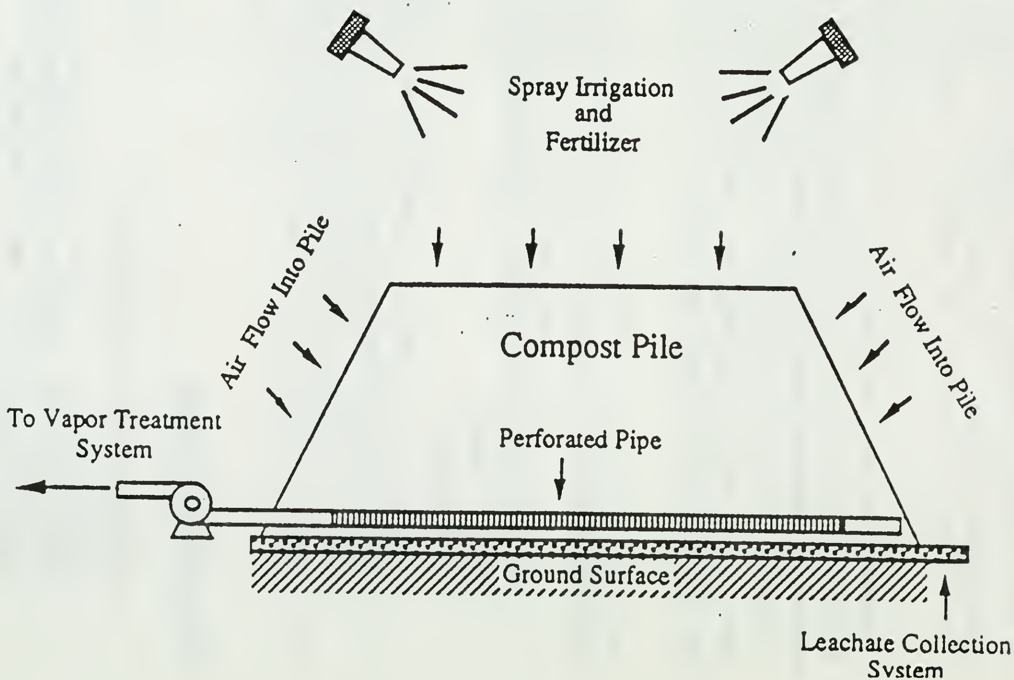
Applicability

- soils contaminated with petroleum fuels (as gasoline, jet fuel, diesel);
- oil sludges;
- polycyclic aromatic hydrocarbons (PAHs including napthalene, anthracene, etc.);
- benzene, toluene, ethylbenzene, and xylene (BTEX);
- some chlorinated solvents.

Potential Advantages

- minimum labour requirements;
- low costs;
- shorter time of treatment than landfarming;
- more positive control of air emission;
- soils with high contaminant levels can be treated.

Composting



Adapted from SOIL REMEDIATION WORKSHOP

Potential Limitations

- presence of heavy metals, chlorinated organics, pesticides, etc. can be toxic to bacteria;
- variable composition of soil may lead to inconsistent results;
- low levels cannot always be achieved.

Treatment Rate

- remediation may take 60 to 90 days to achieve 90 per cent removal.

Estimated Costs

- $15 to $80 per cu.yd.[2]

3. Soil Slurry Bioreactor

The first step in this process is to separate and remove the larger soil particles. The soil is then mixed with water to obtain a slurry of proper consistency. Slurry is mechanically agitated in a bioreactor vessel to keep the solids suspended and to maintain an intimate contact with the bacteria. Suitable amounts of nutrients, water, surfactants and sugars are added to maintain proper levels of active biomass population in the bioreactor. Once the treatment is completed, the slurry is dewatered and the water is further treated and clarified and the clean soil is disposed of.

Applicability

- petroleum hydrocarbon fuels;
- chlorinated organic solvents;
- crude oil, oils and grease;
- PAHs;
- some pesticides.

Potential Advantages

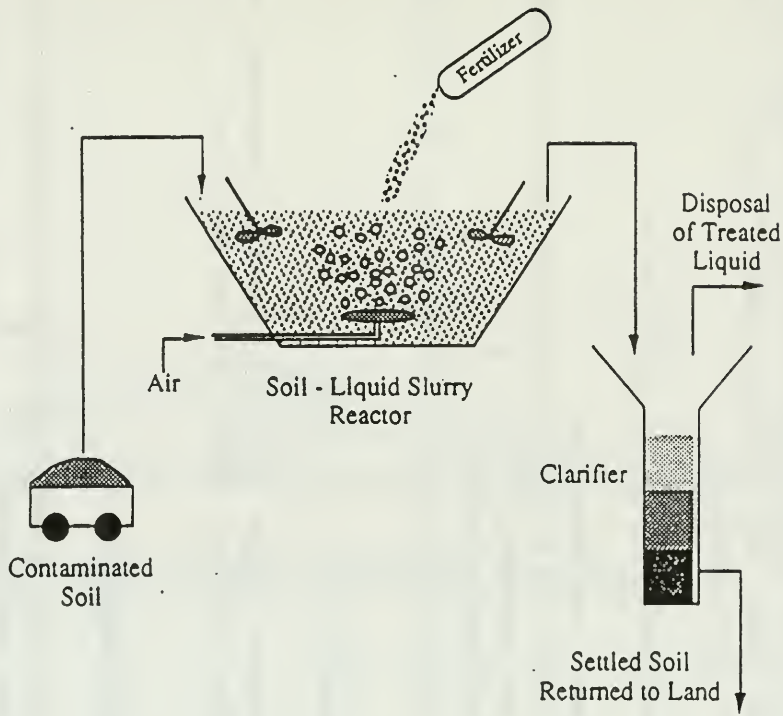
- minimum labour requirements;
- treats higher levels of contaminants;
- a wide range of organics can be treated;
- less space requirements;
- air emissions can be controlled.

Potential Limitations

- presence of heavy metals, pesticides and chlorinated organics may be toxic to the bacteria;
- capital costs for equipment may be expensive;
- contaminants with low solubility are more difficult to treat;
- low cleanup levels are not always achieved;
- operating temperature must be 20° to 30° C.

Estimated Costs

- $30 to $80 per cu. yd.[2]



SOIL SLURRY BIOREACTOR.

Adapted from SOIL REMEDIATION WORKSHOP

4. Low Temperature Thermal Stripping

The excavated soil is heated in a closed chamber to temperatures ranging from 200°C to 260°C to volatilize the contaminants. The off-gases from the soil are then passed through an air emission control system or a recovery system. In some cases, the gases are passed through to a second reactor and incinerated.

The basic components of the operation are:

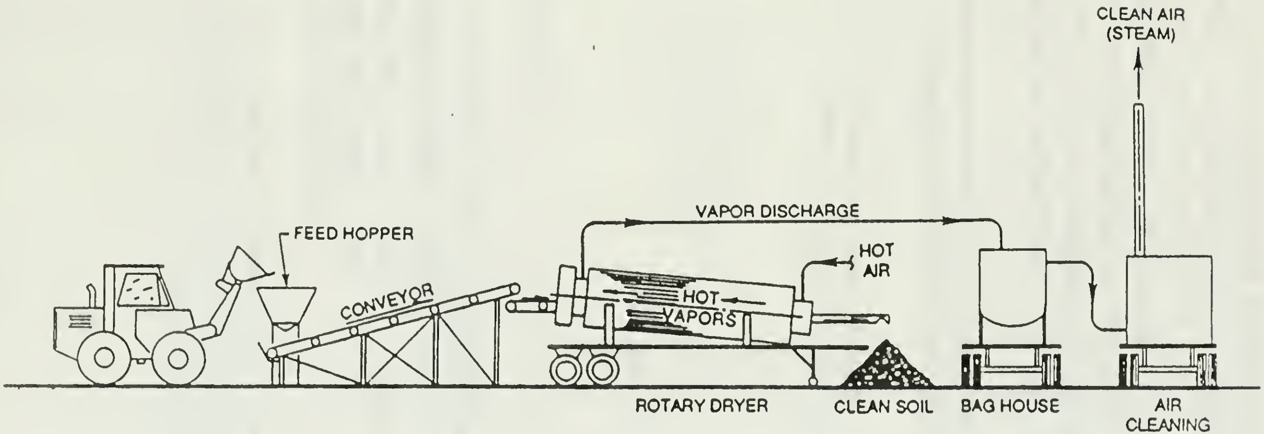
- feeder with screening;
- rotary kiln with indirect infrared heating or indirect heat exchanger;
- air emission control;
- recovery system with activated carbon or an afterburner.

Applicability

Contaminated soils with low volatile petroleum fuels (gasoline, jet fuel, diesel fuel) and pesticides.

Potential Advantages

- volatilize a wider range of petroleum products than in-situ technologies;
- treatment can be accomplished in a short period of time;
- treated soil can be returned to site;
- system is relatively compact and mobile.



LOW TEMPERATURE THERMAL PROCESS.

Adapted from ON-SITE TREATMENT OF SOILS 1989 MANUAL

Potential Limitations

- removes only volatile organic compounds;
- precautions must be taken to avoid explosions within the equipment;
- high levels of metals, fluorides, chlorides, and sulphur may cause problems in the air emission controls;
- high moisture content may reduce efficiency;
- may not be suitable for soils with high percentage of clay and silt;
- may not be capable of handling soils with greater than one percent petroleum hydrocarbon content for some design;
- chlorinated organics require more elaborate air emission control system.

Treatment Rate

- 2 cu. yd. to 6 cu. yd. per hr.

Estimated Costs

- $100 to $165 (US) per cu. yd.[2]
-

>10,000 ton/day:	$90 - $150 (US) per ton;[8]
3,000 to 10,000 ton/day:	$125 - $175 (US) per ton;
<3,000 ton/day:	$175 - $225 (US) per ton;

5. High Temperature Thermal Destruction

This technology utilizes high temperatures as the principal method of destroying organic contaminants. The treatment involves heating excavated soil in a closed chamber to volatilize and destroy organic compounds by converting them to carbon dioxide and water. The off gases are passed through a secondary chamber at higher temperatures to ensure complete destruction of all organic constituents and then through the air emission control system. The destruction and removal efficiency achieved in this treatment exceeds 99.9 percent. The process temperatures during the operation are in the range of 850 to 1200°C.

Types of incineration equipment include:

- rotary kiln;
- fluidized bed;
- infrared thermal;
- pyrolytic.

Applicability

- practically any type of organic contaminant;
- not applicable for metals.

Potential Advantages

- all organics are completely destroyed;
- Destruction and removal efficiency (DRE) is greater than 99.99% with most organic compounds.

Potential Limitations

- presence of halogenated organics may require special air pollution control equipment;
- production of volatile metals, PCB and dioxins;
- feed size limitations for some equipment;
- high fuel requirements;
- high capital costs for incineration equipment;
- high operating costs;
- permits may be difficult to obtain;
- treated soils may be sterile.

Treatment Rate[2]

- treatment rate depends on type of contaminant and its concentration in soil.
- rotary kilns - less than 100 tons/day;
- fluidized beds & infrared thermal - approx. 100 tons/day;
- pyrolytic incinerators - < 10 tons/day.

Estimated Costs[2]

- rotary kilns, fluidized bed and infrared thermal
  - $100 (US) to over $500 (US) per ton;
- pyrolytic incinerators
  - $300 (US) to over $1,000 (US) per ton.

6. Beneficial Reuse

Soils contaminated with petroleum hydrocarbons are incorporated into hot asphalt mix as a partial substitute for stone aggregate.

During the asphalt batching process, the contaminated soil is heated to 260°C to 427°C and passed through a dryer where the lighter petroleum hydrocarbons such as gasoline, kerosene, diesel and heating oils are volatilized. The heavier hydrocarbon residual along with the soil are blended at less than 5 percent of the total feed with other aggregates into the hot asphalt mix. The resultant mixture is used as base material for road bed or parking lots. Dryer exhaust gases may require treatment such as thermal destruction of organic compounds.

Applicability

- soils contaminated with heavier petroleum hydrocarbon fuels;
- not applicable for petroleum wastes because of unknown constituents.

Potential Advantages

- costs are relatively low in comparison with other ex-situ technologies;
- labour and maintenance requirements are low;
- treatment time is short.

Potential Limitations

- asphalt plants are not operated during cold weather;
- not all soils may be suitable for asphalt incorporation;
- transportation is required as the treatment plant may not be located conveniently between on-site and point-of-use for asphalt;

- not widely practised.

Treatment Rates[2]

- treatments rates are determined by the size of the existing asphalt plant. The soil feed is restricted to 5 percent of the total feed in Massachusetts due to uncertainties of its impact on air quality.

Estimated Costs[2]

- $80 (US) per cu. yd. not including excavation and transportation costs.

7. Chemical Extraction

This is a soil washing process which is used to separate the contaminants into respective phase fractions: organics, water, inorganics and particulate soils. It involves mixing the soil with water or water containing a chemical extracting agent to release and remove the contaminant from the soil particles. The extracting reagent may be any one of a lixiviant* such as a solvent, surfactant, chelating agent, an acid or a base. The reagent may dissolve, precipitate and separate the contaminant from the soil. The resulting mixture is mechanically aerated, centrifuged or filtered to separate the extracting reagent with the contaminant from soil. The soil may be washed or aerated to remove residual extracting reagent. The recovered extracting agent is then filtered to remove particulates and treated to remove contaminants. This

technology may also be referred to as solvent extraction/soil washing and soil washing/volume reduction.

* Chemical reagent used to extract, a soluble component from a mixture by washing.

Applicability

With the use of appropriate extracting agents this process can effectively remove any petroleum hydrocarbons and fuel residuals, heavy metals, pesticides, herbicides, PCB, cyanides, wood preservatives, and creosote.

Can be used to treat any soils contaminated with acids, base and heavy metals and any soils with high moisture content.

Potential Advantages

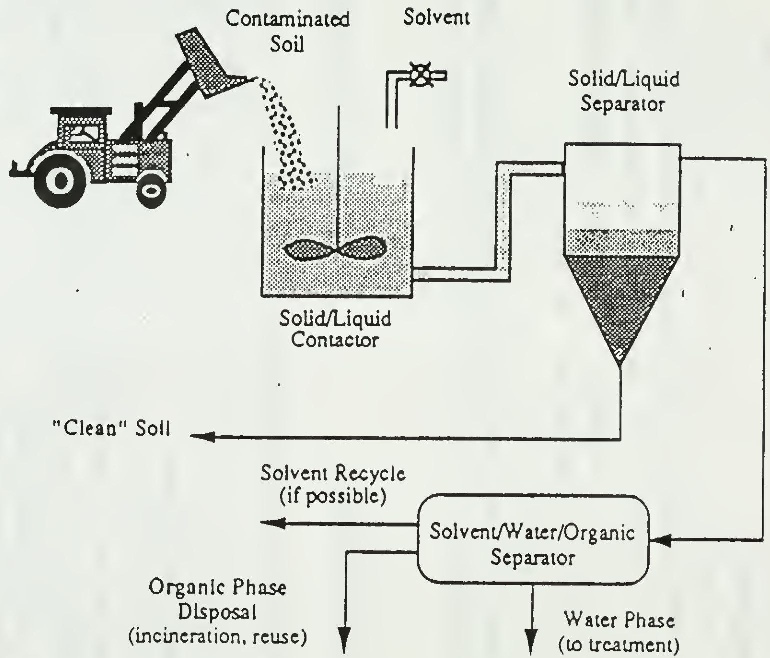
° wide range of applications.

Potential Limitations

° clay content greater than 20 to 30 percent;
° high level of volatile organic carbon may combine with the extracting agent;
° not all organic compounds can be removed effectively.

Treatment Rates[2]

° 0.5 to 10+ tons per hr.



SOLVENT EXTRACTION / SOIL WASHING.

Adapted from ON-SITE TREATMENT OF SOILS 1989 MANUAL

Estimated Costs

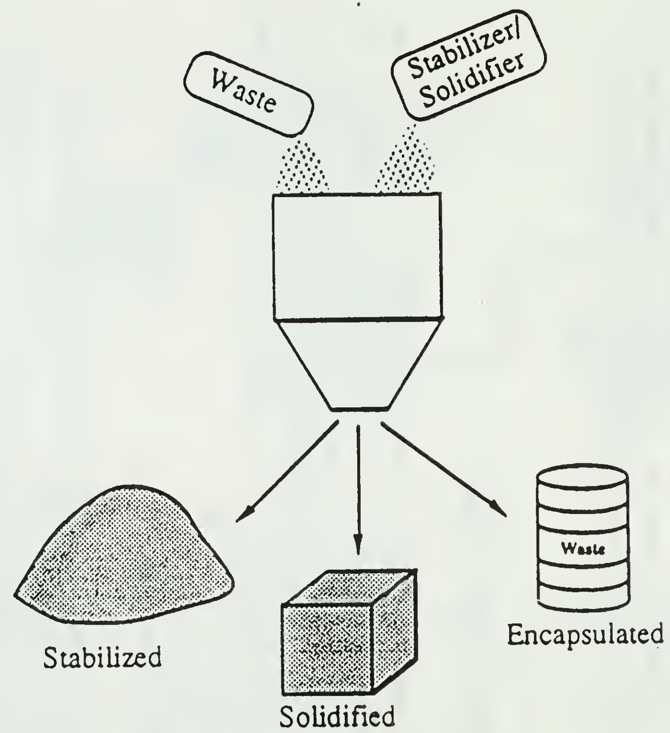
- $90 to $250 (US) per ton (petroleum hydrocarbons);[2]
- $160 (Cdn.) per ton (Toronto Harbour Commission);[9]
- $200 (US) per ton for wood preserving sites;[12]
- $75 - $125 (US) per ton for sites with 5,000 to 10,000 yd. of soil with 70 percent of materials greater than 74 micron;[10]
- $150 to $200 per ton for soil washing/flotation.
- $125 to $250 (US) per cu. yd. for PCB contaminated soil;[11]
- up to $300 (US) per ton for petroleum refinery site.[11]

8. Solidification/Stabilization

The main purpose of this technology is to immobilize the contaminants in the soil for safe disposal or reuse. The process involves the addition of a sufficient quantity of materials that combine physically (solidification) and/or chemically (stabilization) to decrease the mobility of the contaminants in the soil.

Other purposes include:

- limit the solubility of contaminants in the soil;
- detoxify contaminants;
- decrease the surface area through which the transfer and loss of contaminant can occur.



SOLIDIFICATION / STABILIZATION.

Adapted from ON-SITE TREATMENT OF SOILS 1989 MANUAL

Applicability

- soils moderately contaminated with petroleum hydrocarbon fuels;
- soils moderately contaminated with refined petroleum products;
- soils contaminated with heavy metals.

Potential Advantages

- raw materials are inexpensive;
- technology is well established and equipment is readily available;
- least expensive of the ex-situ technologies.

Potential Limitations

- restrictions may be imposed on future land use;
- long term integrity of solidified materials are not well established;
- no test protocols;
- presence of high levels of organics in the soil may interfere with process.

Estimated Costs

- \$30 to \$120 US per cu. m.[2];
- \$100 to \$200 (US) per ton.[6]

C. Selection of Remediation Technology[3]

Before any decision is made to select an appropriate remediation technology, the selection process must consider the following questions in detail:

- what contaminants are present?
- what are the levels?
- how much soil must be treated?
- where is the contaminated soil located?
- what are the cleanup goals?
- how quickly must this be done?
- are there any regulations that prohibit the technology?
- what are the soil characteristics?

SUMMARY OF SOIL REMEDIATION TECHNOLOGIES

In-Situ Technology	Applicable Contamintants	Advantages	Limitations	Costs* $/cu.yd.	Costs* $/ton
Volatilization	°gasoline, diesel, kerosene, jet fuels chlorinated solvents	°low costs °minimum disruptions	°volatiles only °depends on soil and moisture conditions °air emission	10-50	
Bioremediation	°same as above and PAH's	°low costs °low manpower	°heavy metal pesticide and other toxics	15-60 50-100 Cdn/N.Ont	
Soil Leaching	°petroleum products, heavy metals, salts	°low costs	°timeframe depends on soil conditions °migration of contaminants	15-120	
Isolation/ Containment	°petroleum products, heavy metals, salts	°low costs °proven technology	°no reduction in contaminants °depth °monitoring	60-100 °slurry trench 7-13/yd °capping 1-5/sq.ft	
Vitrification	°petroleum products, PAH's, heavy metals, salts	°destruction of petroleum products and organics	°depth °expensive	115-170	275-400

* Quoted in US dollars except where indicated

SUMMARY OF SOIL REMEDIATION TECHNOLOGIES

Ex-Situ Technology	Applicable Contaminants	Advantages	Limitations	Costs* $/cu.yd.	Costs* $/ton
Surface Bioremediation (Land Farming	°light petroleum products °oil sludge °crude oil, PAH's, tank bottoms	°well established °low costs °low manpower required	°require large land area °temperature dependent °2 to 6 months required	10-40	25-50
Enhanced Bioremediation a) Composting b) Slurry Bioreactor	°petroleum hydrocarbons, crude oil and refined oils, chlorinated solvents, PAH's, ethylene glycol, some pesticides	°treats higher levels of contaminants °less space and manpower required	°temperature between 20°C to 30°C °cleanup levels not certain °presence of other compounds may be toxic	a) $15-$80 b) $30-$80	
Low Temperature Stripping a) heat only b) steam	°light petroleum products, chlorinated solvents, phenols, vinyl chloride, ammonia H_2S	°job completed in short time °equipment compact and mobile	°high equipment costs °corrosion problems °emission controls	$100-$165 $50-$100	

SUMMARY OF SOIL REMEDIATION TECHNOLOGIES

Ex-Situ Technology	Applicable Contaminants	Advantages	Limitations	Costs* $/cu.yd. $/ton
High Temperature Thermal Destruction	°any type of organic contaminants	°quick °effective °treated soil can be used as fill	°not for metals, high fuel requirement, capital costs, permits not easily obtainable	$100-$500 (see text)
Beneficial Reuse Asphalt Incorporation	°crude and petroleum products	°low costs °reuse °use of existing equipment	°not for cold weather °limited for certain soils °transportation	80 not including excavation
Chemical Extraction (Soil Washing)	°petroleum hydrocarbons, PCB, pesticides, heavy metals, salts, cyanides, wood preservatives	°wide range of chemical contaminants °soils with high moisture	°not for soils with clay content and heavy soils	$90-$250/$75-$125 $185 for wood preservatives
Solidification/ Stabilization	°petroleum hydrocarbon, inorganic salts, heavy metals	°well-established °equipment available	°restriction on future use °no test protocols	$25-$100

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SUMMARY

This report presents summary descriptions of technologies which have been developed beyond the experimental stage. They have been proven and are now available on the market for cleaning up contaminated soils.

The remediation technologies are divided into two categories:

- In-situ technologies are those which are performed with the contaminated soil remaining in-situ or in-place at site. These include in-situ volatilization, bioremediation, soil leaching, isolation/containment and vitrification.

- Ex-situ technologies are those which involve the removal usually by excavation, of the contaminated soil and the soil is treated at a different location on site or hauled off-site. These include surface and enhanced bioremediation, low temperature stripping, high temperature thermal destruction, beneficial reuse, chemical extraction (soil washing), solidification/stabilization and isolation/containment.

An attempt was made to compare the costs of the various soil remediation technologies. This has been difficult simply because there are no standard methods of calculating cost estimates for treatment based on unit of soil treated.

Total cost of treatment would be determined by number of fixed costs which must be considered.

1) Costs involved with setting up equipment, transporting
2) Labour and operating
3) Regulatory compliance
4) Disposal of treated soil.

C:\TSA\ODA\SUMMARY

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APPENDIX

Bioremediation

From the statistics compiled by the U.S. Environmental Protection Agency, in 1989, bioremediation was selected as a cleanup option at 22 contaminated locations representing 10.5% of the Superfund sites.[13]

Bioremediation is a process by which the organic contaminants are destroyed by the action of the naturally occurring soil bacteria. Some bacteria are capable of obtaining energy by breaking down organic compounds notably petroleum hydrocarbons and converting them to carbon dioxide and water.

Bioremediation involves the stimulation of growth and activity of these microorganisms in the contaminated soil by adding oxygen and nutrients. Those factors which are considered important in the success of this technology for cleaning up contaminated soils include:

a) bacterial population
b) contaminant levels
c) process conditions (moisture and oxygen)
d) soil conditions
e) temperature

During recent years, bioremediation has been receiving increased attention as a site cleanup option in the United States as a result of the Superfund Amendment and Reauthorization Act (SARA) of 1986. The Act imposes the cleanup of a contaminated site with permanent remedies rather than simply moving the contaminated materials and burying them somewhere else. This technology has some attractive features as an in-situ treatment of contaminated soils because it has the potential for just such a permanent remedy.[14]

In the context of soil remediation, several words with a prefix "bio" have been coined to describe the action of microorganisms. These are frequently found in the recent literature:

biodegradation: describes the process of decomposition of contaminants by bacterial action

bioreclamation: refers to the use of bacteria to destroy contaminants in-situ to reclaim contaminated soils or groundwater.

biorestoration: refers to the process of removing contaminants in the soils to acceptable levels

biotransformation: refers to the change or conversion of toxic contaminants into innocuous forms through the use of bacteria

biotreatment: describes any processes which require the use of bacteria to destroy contaminants in the soil

biostimulation: refers to the process of adding nutrients, moisture and/or bacteria to enhance bacterial activity for destroying contaminants in the soil.

It should be noted that biological processes are only applicable for removing organic contaminants in the soil. Inorganic materials are rarely destroyed by bacterial action and may even prevent or inhibit their activity.